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PATENT APPLICATION

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APPARATUS AND METHOD FOR DETECTING DEFLECTION OF A TOWER

[0001] This application claims benefit from U.S. Provisional Application No. 60/427,623, filed November 19, 2002.

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0002] This invention relates in general to towers and other upright structures, and in particular to an apparatus and method for detecting and measuring tower deflection.

2. Description of the Related Art

[0003] Towers and other similar free-standing upright structures are used in a variety of applications, for example, as radio and telecommunications antennas or to secure and support various types of payloads. These structures are often subject to forces caused by wind or other phenomena. These forces can cause swaying, bending, torsion or other movement of the tower, which can result in translational and rotational deflection, in particular to the upper portion of the tower relative to the tower's more stable and securely-fastened bottom portion.

[0004] This deflection can detrimentally affect particular tower applications. For example, if a tower is supporting a payload which comprises a device requiring accurate aiming, such as a directed-energy weapon, small tower deflections may move the energy beam produced by the weapon off a target located a long distance from the tower, requiring correction in response to the tower deflection to maintain the proper aim of the weapon. If the tower deflection could be detected and measured initially, such an occurrence, as well as other similar occurrences, could likely be prevented.

[0005] A need exists, therefore, for an apparatus and method for detecting and measuring real-time deflection of a tower. Further, for those tower applications which involve supporting a payload, a need exists for an apparatus and method which would allow for adjusting components in the payload in response to any measured deflection.

SUMMARY OF THE INVENTION

[0006] The present invention provides a method of detecting deflection and twisting rotation of an upright structure. At least one laser device is positioned proximate to a first location on the structure. At least one target is positioned proximate to a second location on the structure. The at least one laser device emits at least two parallel laser beams that strike the at least one target at reference locations that indicate a reference position for the upright structure. The laser beams can be emitted either periodically or continuously. The position of the points where the laser beams strike the at least one target are monitored for changes. Any differences between the points where the laser beams strike the at least one target and the reference locations are calculated to determine any lateral deflection and twisting rotation of the structure relative to the reference position from the first to the second location.

[0007] A feature of the present invention is that the upright structure is a tower. Another feature is that the at least one laser device is disposed at or near a base of the structure and the at least one target is disposed at or near a top of the structure. Another feature is that at least one camera is focused at the at least one target to analyze any differences between the laser beam receipt locations and the reference locations with at least one image analyzing computer. Another feature is that the at least one target may have at least one pixel grid that is struck with the laser beams. Another feature is that at least one tube may be mounted between the first location and the second location, and the laser beams may pass through the at least one tube. Another feature is that the at least one laser device may be stationarily mounted relative to the first location and the at least one target may be stationarily mounted relative to the second location. Another feature is that the reference position of the tower is substantially zero deflection and zero twist rotation.

[0008] Another aspect of the present invention provides a method of measuring deflection of an upright structure. A first module is positioned proximate to a first location on the structure, the first module having at least one laser. A second module is positioned proximate to a second location on the structure, the second module having a target. A laser beam is emitted from the laser which strikes a reference location on the target. Any movement of the laser beam on the target relative to the reference location is discerned, and the amount of deflection of the structure based upon any differences in movement is calculated.

[0009] A feature of this aspect of the present invention is that a tube is mounted from the first to the second module. Another feature is that the laser beam emitted from the laser passes through the tube and strikes a reference location on the target. Another feature is that one of the modules is at or near a base of the upright structure and the other of the modules is at or near a top of the upright structure. Another feature is that the first module is disposed at or near the base of the upright structure and the second module is disposed at or near an upper end of the upright structure. Another feature is that any movement of the laser beam on the target is discerned by using a camera focused on the target, the camera being located adjacent the target and offset from the laser beam. Another feature is that the target comprises a pixel grid and any movement of the laser beam on the target is discerned by using a pixel element analyzing computer. Another feature is that the reference location corresponds to zero deflection of the upright structure.

[0010] Another aspect of the present invention provides an apparatus for detecting lateral deflection and twisting rotation of an upright structure. The apparatus includes at least one first module adapted to be mounted adjacent a first location of the structure, at least one second module spaced a distance from the at least one first module and adapted to be mounted adjacent

a second location of the structure, a laser emitter disposed at the at least one first module, the emitter capable of emitting at least one laser beam, a target disposed on the at least one second module, the target being capable of receiving the at least one laser beam produced by the emitter, and a detection device that detects any differences between the locations of a plurality of parallel laser beams that strike the target at any time and predetermined reference locations on the target to determine any deflection and rotation of the first location of the upright structure relative to the second location of the upright structure. A feature of this aspect of the present invention is that the emitter is capable of emitting a plurality of parallel laser beams. Another feature is that the upright structure is a tower, and the first and second locations are substantially fixed relative to each other. Another feature is that a tube extends between the at least one first and second modules for enclosing the laser beams. Another feature is that the detection device comprises a camera mounted adjacent to the target such that a line extending from a lens of the camera to the target is at an inclination relative to the laser beams. Another feature is that the target comprises a pixel grid.

[0011] Another aspect of the present invention provides a tower which includes an elongated structure having a base and a top, at least one laser device disposed at a first location on the structure, at least one target disposed at a second location on the structure for receiving a laser beam from the at least one laser device, and a detection device that monitors the at least one target to determine any change in position of where the laser beam strikes the at least one target, thereby indicating deflection of the tower. A feature of this aspect of the present invention is that at least one tube extends from the at least one laser device to the at least one target. Another feature is that the detection device comprises a camera mounted adjacent to the at least one target

such that a line extending from a lens of the camera to the at least one target is at an inclination relative to the laser beams. Another feature is that the at least one target includes a pixel grid.

Brief Description of the Drawings

[0012] The various aspects of the invention will now be described by way of example only with reference to the accompanying drawings, in which:

[0013] FIG. 1 is a profile view of a tower erected on a support surface and supporting a payload.

[0014] FIG. 2 is a schematic profile view of a system constructed according to the invention for measuring deflection of the tower of FIG. 1, the system comprising a laser module and a target module.

[0015] FIG. 3 is a plan view of the base of the tower of FIG. 1 with the laser module of FIG. 2 installed.

[0016] FIG. 4 is a plan view of the upper portion of the tower of FIG. 1 with the target module of FIG. 4 installed.

[0017] FIG. 5 is a bottom plan view of a target of the target module of FIG. 2 during operation.

[0018] FIG. 6 is a schematic view of an electronic collection and data conversion system according to the invention.

[0019] FIG. 7 is a schematic profile view of an alternative embodiment of the measurement system according to the invention, the embodiment using an optional target module.

Detailed Description of the Preferred Embodiment

[0020] FIGS. 1 through 7 illustrate two embodiments of an apparatus for measuring translational and rotational deflection of an upper portion of a tower. Deflection is primarily caused by wind exerting a force on the tower, though other forces may also act on tower to cause deflection.

[0021] FIG. 1 shows a tower 11 constructed on support surface 13. Tower is preferably formed from a lattice framework 15 of metal members, as shown, though tower 11 may be of other types, such as a polygonal single-pole tower or a tapered cylindrical single-pole tower (not shown). A payload 17 is supported on the upper portion of tower 11, which may be 300ft or more above surface 13. Payload 17 may be of various types, including communications equipment or other electronic equipment.

[0022] To measure deflection and twisting rotation of tower 11, a preferred embodiment utilizes a two-piece measurement system that is mounted to or near tower 11. FIG. 2 shows system 19, comprising one laser module 21 and one target module 23. In an alternative embodiment, one or more laser modules 21 and/or one more target modules 23 at various locations may be utilized. Laser module 21 is securely mounted on support surface 13 with mounting plate 25 at or near the lower end of tower 11 (FIG. 1). FIG. 3 is a plan view of the lower end of tower 11 showing laser module 21 installed near the central axis 27 of tower 11. Referring again to FIG. 2, at least one and preferably two lasers 29 are rigidly mounted within module 21 for directing laser beams (not shown) vertically upward near and parallel to line 31. Laser module 21 is preferably mounted using a precision bracket, allowing the laser beams to be precisely vertical. Lasers 29 are preferably mounted approximately 1.5in apart.

[0023] Lasers 29 are preferably 30mW, 632nm (red) lasers, available from Cemar Electro, Inc. of Champlain, NY, though lasers 29 may be any power or produce any light frequency that satisfies the operational requirements of system 19, as described herein. In the preferred embodiment, the size of each laser beam is approximately 3mm as it exits laser 29, widening to approximately 6mm at 300ft. At least one cable 33 extends into module 21 to carry electrical power and control data to and from lasers 29. Preferably, at least one tube 35 is sealingly connected to the upper end of laser module 21 and is preferably coaxial with line 31, tube 35 preventing airborne contaminants or other objects from interrupting or degrading the beams created by lasers 29. The beams from lasers 29 travel upward through tube 35 and into target module 23. Alternatively, lasers 29 may travel upward without using the tube 35.

[0024] Target module 23 is mounted at an upper portion of tower 11 (FIG. 1), as shown in FIG. 4, preferably directly above laser module 21 (FIG. 3). Target module 23 has a box-shaped enclosure 36 that is sealingly connected to the upper end of at least one tube 35 at joint 37, which is offset from the center of module 23. A target surface 39 is formed on the inner surface of upper wall 41 of target module 23, surface 39 having a color providing high contrast relative to the color of the beams from lasers 29.

[0025] Referring to FIG. 5, the laser beams strike target 39, forming visible dots 43, 45. Dots 43, 45 have a fixed position, due to lasers 29 being mounted on support surface 13 (FIG. 2), whereas target 39 moves with target module 23 as tower 11 is deflected. By measuring the relative change of the position of dots 43, 45 on target 39, as shown by phantom dots 47 at an actual receipt location, the amount of deflection, in translation or rotation, of tower 11 may be calculated. For example, a change of both in the x or y direction the same amount indicates lateral deflection in the y-direction, but no rotation. A change in x or y direction of one relative

to the other indicates twisting rotation of the tower. While two dots 43, 45 are shown, the number of dots 43, 45 will be equal to the number of lasers 29 (FIG. 2) in use.

[0026] Referring again to FIG. 2, a camera 49, such as a type available from DVT Corporation of Norcross, GA, is mounted to a lower portion of module 23 for use as part of a detection device for measuring the change in position of dots 43, 45. Camera 49 is mounted in a position offset from the center of module 23 and at an angle relative to line 31, camera preferably being approximately 1.5ft from target 39. This orients the sightline of camera 49, indicated by line 45, for allowing camera 49 to image an area 51, shown as a broken line in FIG. 5, of target 39 surrounding dots 43, 45. Camera 49 has a lens 53, which is 8mm in the preferred embodiment, for focusing light entering camera 49 onto an imaging device 55, which may be, for example, a charge-coupled device (CCD). Cables 57 carry electrical and data signals to and from camera 49.

[0027] Imaging device 55 in camera 49 has an array of light-detecting elements (not shown), or pixels, that produce a digital signal when light falls on the pixels. The light from each dot 43, 45 reflected from target 39 is detected as an image by a discrete set of these elements, and a software program, which may be run on a computer within camera 49, is used to analyze the image, determine the centroid of each dot 43, 45, and output the location of the dots in x and y coordinates. Since camera 49 is located off the axis of the laser beams, circular dots 43, 45 will appear to be ellipses, though this will not affect the calculations, as the software will determine the centroids to be in the same locations as with circular dots 43, 45. Camera 49 periodically monitors and takes readings of the positions of dots 43, 45, the frequency preferably being within the range of 10-20,000Hz. The monitoring preferably occurs at a high rate of frequency and

preferably in real time. The frequency of monitoring can depend upon, among other factors, the amount of data being monitored and the speed of the computer performing the monitoring.

[0028] In operation, when camera 49 and target 39 move relative to dots 43, 45, which remain stationary as module 23 moves with tower 11, the light from dots 43, 45 falls on pixels at a location on imaging device 55 that is shifted from the previous location. The light is then detected on a different set of pixels, and the software outputs the new location of the centroid of each dot 43, 45, allowing the amount of deflection of tower 11 to be calculated from the change in the positions of dots 43, 45 on target 39.

[0029] FIG. 6 is a schematic showing one embodiment of an electronic collection and data conversion system using the output of camera 49 to make adjustments based on measured deflection of tower 11. In this embodiment, camera 49 outputs the x and y coordinate data for dots 43, 45 in ASCII characters through cable 57 to an Ethernet-to-serial interface converter 59. Converter 59 then outputs the data through cable 61 to an SDM-SI04 interface 63, which can be programmed as needed to create formatted output strings from the received characters. These strings are output through cable 65 to data logger 67, which records the data and calculates the translation and rotation of tower 11 between data readings. The deflection data is then output through cable 69 to a computer 71 that controls components of payload 17 (FIG. 1) of tower 11. Thus, the present invention is used to detect real-time deflection of tower 11 to allow for adjusting components in payload 17 in response to the measured deflection. For example, if payload 17 comprises a device requiring accurate aiming, such as a directed-energy weapon (not shown), small deflections of tower 11 may move the energy beam off a target located a long distance from tower 11. The present invention allows for correction in response to a measured deflection of tower 11 to maintain the proper aim of the weapon. Alternatively, camera 49 may

include one or more of the data formatting components described above, and camera 49 may output the deflection data directly to computer 71 through cable 57.

[0030] An alternative embodiment of the invention is shown in FIG. 7 as measurement system 73, with target module 23 being replaced by optional target module 75. Target module 75 is mounted at an upper portion of tower 11, preferably directly above laser module 21. Target module 75 has a box- or tube-shaped enclosure 76 that is sealingly connected to the upper end of tube 35 at joint 77, which is preferably coaxial with the vertical centerline of module 75 and line 31. At least one pixel grid 79, similar to imaging device 55 (FIG. 2), is located within module 75 for use as part of a detection device for determining the positions of dots 43, 45 (FIG. 5), which are formed on face 81 of grid 79 by beams from lasers 29. Grid 79 is mounted in module 75 such that face 81 is approximately normal to and centered on line 31. Face 81 comprises a plurality of discrete pixel elements (not shown) that produce a digital signal when light from lasers 29 strike the elements, allowing the positions of dots 43, 45 on face 81 to be detected directly. Cables 83 carry electrical power and data signals to and from grid 79. Grid 79 will typically be connected to computer 71 through a plurality of data analysis and formatting components, as shown for camera 49 in FIG. 6. While shown as having one grid 79 for detecting all of dots 43, 45, module 75 may have two or more grids 79, each for detecting one or more dots 43, 45.

[0031] In operation, when pixel grid 79 moves relative to dots 43, 45, which remain stationary as module 75 moves with tower 11, the light from dots 43, 45 falls on pixels at an actual receipt location on grip 79 that is shifted from the previous location. The light is then detected on a different set of pixels, and pixel grid 79 outputs the new set of pixels detecting each dot 43, 45.

This allows translational and rotational deflection of tower 11 to be calculated from the change in the positions of dots 43, 45 on face 81.

[0032] The present invention has several advantages. The invention provides a simple and low-cost apparatus and method for detecting and measuring deflection of a tower or similar object, and the precision of the system is limited only by the rate of data capture and the resolution of the camera or pixel grid of the target module. The system may be easily attached to or removed from an existing structure or may be incorporated in new construction.

[0033] While the invention has been described herein with respect to a preferred embodiment, it should be understood by those that are skilled in the art that it is not so limited. The invention is susceptible of various modifications and changes without departing from the scope of the claims. For example, if twisting rotation is not a measurement that is needed, a single laser beam would be sufficient. Also, the lasers could be mounted at the upper end of the tower and the target at the base.